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Diurnal and Seasonal Fluctuations in Moisture Content of Pinyon and Juniper

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Fluctuations in moisture content of pinyon and juniper trees are important from the standpoints of fire and hydrology in the pinyon-juniper type. In the case of fire, both those interested in use of fire for juniper control and those interested in fire suppression are concerned with moisture content of fuels. In the case of hydrology, studies of moisture-content fluctuations may shed some light on moisture losses from the soil. This paper presents the results of a series of moisture determinations in the twigs and leaves of pinyon (Pinus edulis Engelm.), Utah juniper (Juniperus osteosperma (Torr.) Little), alligator juniper (J. deppeana Steud.), and one-seed juniper (J. monosperma (Engelm.) Sarg.).

Review of Literature

Diurnal Fluctuations

Moisture fluctuations have been published for many species of plants, but not pinyon or juniper. In all reported cases, moisture content is maximum at night and minimum in midafternoon. Diurnal fluctuations occur because water loss during the day is greater than water uptake, and water uptake at night exceeds water loss (Kramer and Kozlowski 1960).[2] Changes in the diurnal pattern usually follow meteorological conditions (Halevy 1960). In Bartlett pears, the general diurnal pattern held regardless of the season (Ackley 1954).

Seasonal Fluctuations

Because of cold or frozen soil and warm, dry air, conifers are often critically dry in winter (Boyce 1961). This condition is commonly called "winterkill."

Detailed investigations of moisture content of conifers have been reported less often than winterkill, but several species have been studied. Gibbs (1958) has analyzed moisture content records of many species, and has determined that species have their own characteristic water patterns. Pinus strobus at Montreal, Canada, for example, has a low point in early May and a high in mid-September (Gibbs 1958). P. ponderosa in Idaho, on the other hand, has a high moisture content in March (Parker 1954). P. rigida had a higher moisture content in summer than in winter (Meyer 1928).

The seasonal fluctuations are not as consistent nor as easily explained as diurnal fluctuations. Different seasonal patterns of

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[2] *Names and dates in parentheses refer to Literature Cited, p. 7.*

moisture apparently occur because of differential behavior of stomates. Although stomates usually close at night and open during the day (Kramer and Kozlowski 1960), not all species behave in this fashion. In mature conifer leaves, the stomatal action is incomplete (Parker 1956). Guard cells of southwestern junipers are partially lignified,[3] which would probably retard stomatal action. Stomates of some species may close during dry periods, which would retard transpiration and allow moisture content to increase (Kosikova 1956, other references reviewed by Kramer and Kozlowski 1960). Oppenheimer (1953), who has made an extensive study of such mechanisms, proposes the following nomenclature for various reactions:

Oligohydric--plants whose stomata close during drought, with lowered transpiration and increased moisture content.

Polyhydric--plants whose stomata remain open during drought, with increased transpiration and decreased moisture content.

Isohydric--plants with little seasonal fluctuation in moisture content ("homoiohydrous" according to Walter 1955).

Poikilohydric--plants with considerable seasonal fluctuation in moisture content ("poikilohydrous" according to Walter 1955).

Oppenheimer (1953) suggested that an oligohydric pattern is usual for conifers. Oligohydric patterns have been reported for P. strobus, Tsuga canadensis, and Larix europea (Gibbs 1958), but polyhydric patterns have been found in P. ponderosa (Parker 1954), Abies balsamea, and Picea rubens (Clark and Gibbs 1957).

[3] *Personal communication with T. N. Johnsen, Jr., U.S. Agr. Res. Serv., Flagstaff, Ariz. 1962.*

Methods

Species and Locations

Mature pinyon and one-seed juniper trees were observed near Winona, Arizona, and Utah and alligator juniper trees were observed about midway between Williams and Ash Fork, Arizona. Rainfall at these locations generally comes in two distinct periods, one from December through April and another in July, August, and early September (fig. 1). At each location, a tree of each species was located so that one soil moisture sample would suffice for the two trees. Ten trees of each species were selected for study. Utah juniper trees growing on a dry hillside and adjacent to a flowing stream near Sedona, Arizona, were also observed.

Samples and Measurements

The sample of tree material consisted of 100 to 200 grams of twigs and attached leaves. The twigs were one-fourth inch or less in diameter. Wet- and dry-bulb temperatures were taken at a shaded location 48 inches above the ground at the time of sampling to determine temperature and vapor-pressure deficit. Light intensity readings with a photoelectric cell and translucent filter were also made when diurnal fluctuations were being studied.

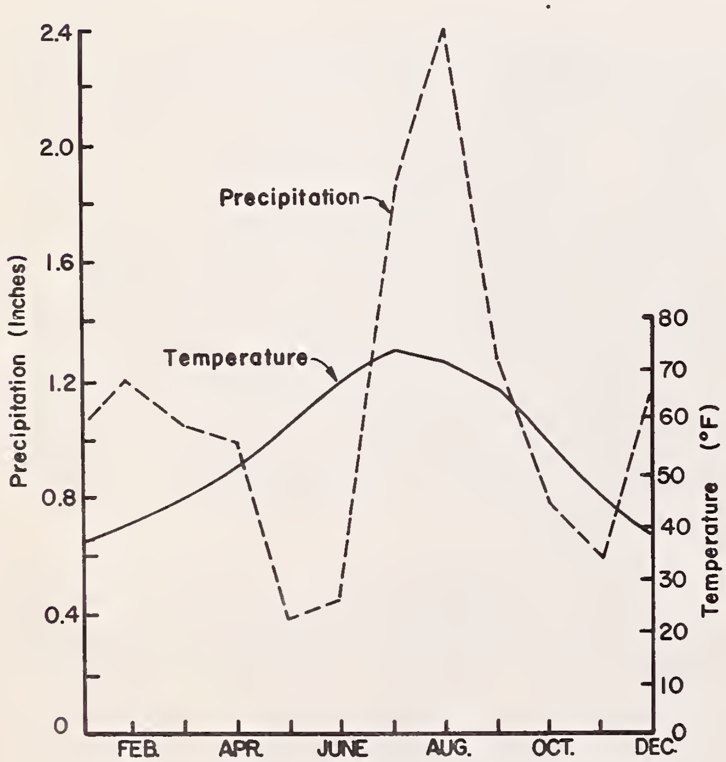
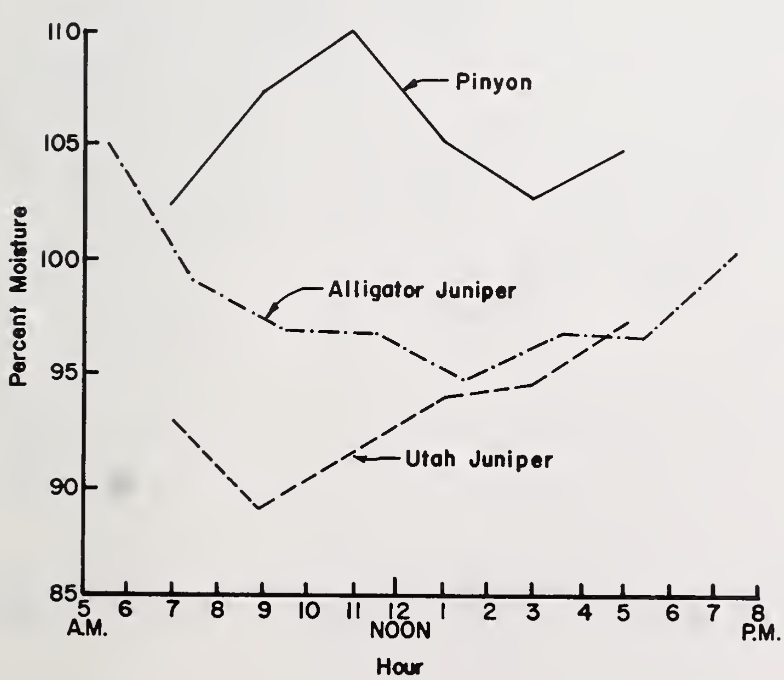


Figure 1.--Seasonal trends in precipitation and temperature at Ashfork, Arizona (Smith 1956).

Diurnal fluctuations were determined in early summer, late summer, winter, and spring by sampling 10 trees at 2-hour intervals from daylight to dark. A different set of 10 trees was selected for each sampling date.

Seasonal patterns were determined by collecting sample material at approximately 2-week intervals from February 1957 through January 1958, and in July and August 1958. The same trees were used throughout the study. Since the trees were quite large--about 15 feet in both height and crown diameter--and the sample size was about 100 grams, harvesting of sample material probably had little effect on the trees. Seasonal samples were collected at 4 hours after sunrise to help standardize conditions. This resulted in a nearly constant solar angle from March through October, but the solar angle from November through February was somewhat less.

One soil sample was collected for each tree location at each sampling date in the 3- to 12-inch zone. This sampling depth included virtually all of the C horizon of the soil at the Winona location, and the upper half of the C horizon at the Ash Fork location. Both tree and soil samples were weighed in the field, dried in the laboratory at 104° C. for 48 hours, and weighed to determine moisture loss.



Results and Discussion

Diurnal Patterns

The different species of junipers uniformly showed a midday depression of moisture content during the summer months. This pattern is represented by the graph for alligator juniper in figure 2. This graph is similar to the graph of relative humidity, or graph of inverse of temperature or light intensity. Inverse moisture contents of junipers were, in fact, highly correlated with temperature and light intensity for the samples collected during the summer (table 1). Figure 2 is the classical curve presented in the literature, and can probably be adequately explained by the fact that absorption lags transpiration when potential transpiration rates are high. The correlations with temperature and light were probably as good as any such fit could be, since the correlation coefficients were about the same as the correlation coefficient between paired trees of Utah juniper and alligator juniper under identical situations ($r = 0.790$).

During the winter months, the significant relationship between juniper moisture content and meteorological conditions was lost. Samples collected in late March and early April had no clear pattern. Samples collected in January had an early-morning dip, followed by an increase through the rest of the day. This pattern is represented by the graph for Utah juniper in figure 2. The shape of this curve suggests that water uptake was limited by low soil temperature or low internal temperature of the trees. These temperatures would probably lag behind air temperature by

Figure 2.--Representative diurnal patterns of moisture content: pinyon during winter, alligator juniper during summer, Utah juniper during winter. Graphs of junipers are also representative of other species of junipers on these dates.

Table 1.--Diurnal patterns of moisture content of juniper and pinyon twigs and leaves and correlations with temperature and light

Species and date	Air temperature range, °F.	Type of pattern	Correlation coefficient of moisture content with-- Air temperature	Light intensity
One-seed juniper:				
Jan. 7, 1958	20-49	Early morning drop then increase	-0.116	-0.420
Mar. 28, 1957	25-62	None		
June 24, 1957	47-93	Inverse with temperature		
July 1, 1958	48-94	Inverse with temperature	-.673**	-.716**
Sept. 3, 1957	44-83	Inverse with temperature		
Utah juniper:				
Jan. 9, 1958	34-50	Early morning drop then increase	+.185	+.063
Apr. 4, 1957	30-53	None		
June 25, 1957	57-93	Inverse with temperature	-.886**	-.750**
Sept. 4, 1957	53-86	Inverse with temperature		
Alligator juniper:				
Jan. 9, 1958	34-50	Early morning drop then increase	-.275	-.266
Apr. 4, 1957	30-53	None		
June 25, 1957	57-93	Inverse with temperature	-.887**	-.736**
Sept. 4, 1957	53-86	Inverse with temperature		
Pinyon:				
Jan. 7, 1958	20-49	Morning rise, afternoon decrease	-.144	-.127
Mar. 28, 1957	25-62	Morning rise, afternoon decrease		
June 24, 1957	47-93	None		
July 1, 1958	48-94	None	-.078	+.063
Sept. 3, 1957	44-83	Decline throughout		

**Indicates significance at the .01 level. Correlation coefficients calculated within days.

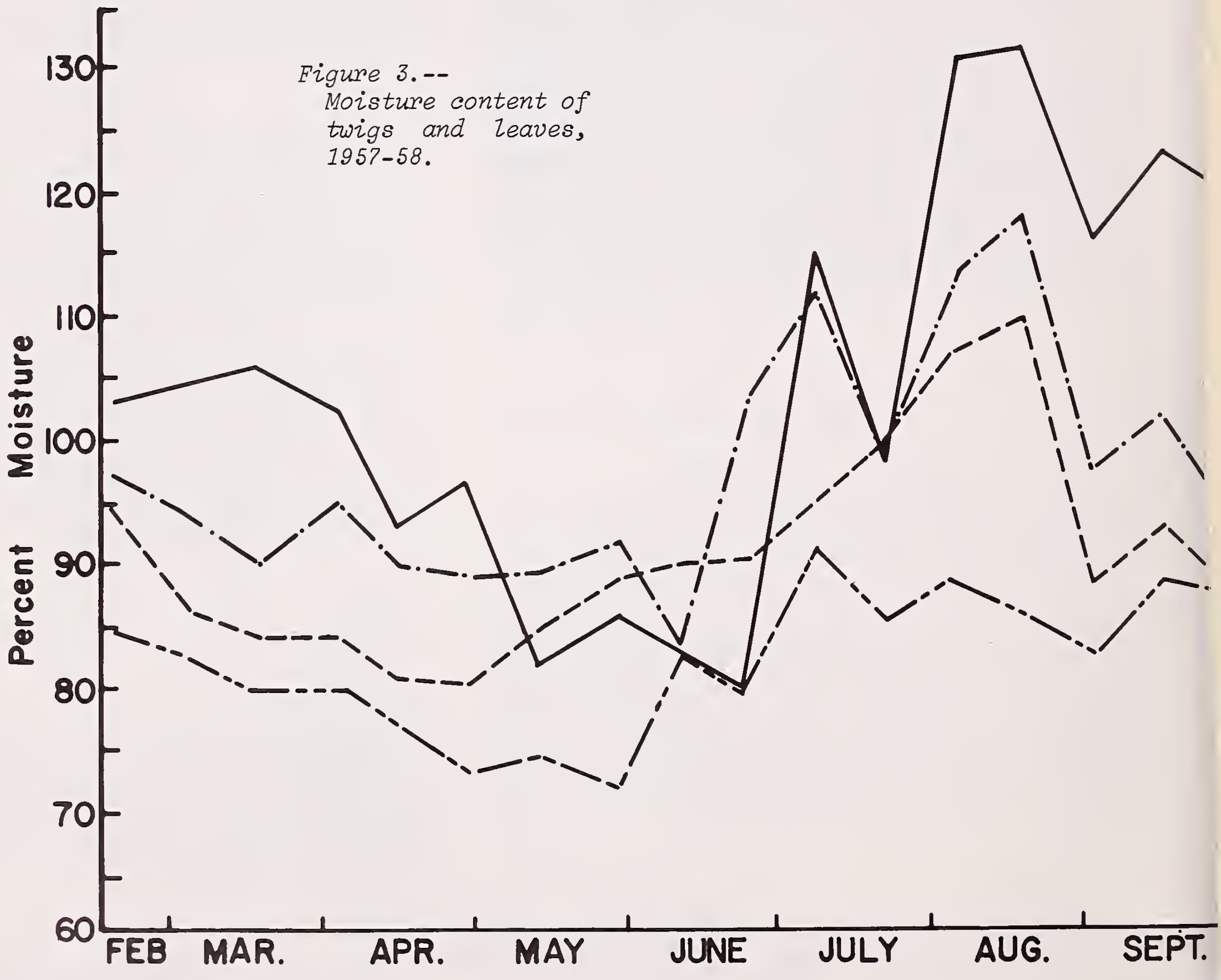


Figure 3.--Moisture content of twigs and leaves, 1957-58.

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an hour or two. During early morning in winter, temperatures were near or below freezing about 48 inches above the ground. Since soil temperature and internal stem temperature were not measured, a mathematical correlation was not possible.

Moisture content samples of pinyon were entirely unlike those of junipers. Early summer samples followed no distinct pattern. The samples collected in September gradually declined in moisture content through the day, but there was no upturn at the end of the day as for the junipers. There was no correlation of moisture content for pinyons with meteorological conditions. Apparently, pinyon leaves have some mechanism to retard the rate of moisture loss that would otherwise occur during summer days, while the mechanism in junipers is not fully adequate.

Pinyon did have a regular pattern for the January and March samples (fig. 2). Moisture content rose in the early morning, then dropped in the afternoon. This pattern is not clearly related to meteorological conditions.

Analysis of variance showed differences between moisture content of samples at times within days to be significant at the 1-percent level, except for the July 1 sample of pinyon and the January samples. For the January samples only, one-seed juniper showed significant differences between times, and that significance was at the 5-percent level. About 60 percent of the total sums of squares were associated with differences between trees; this shows the increase in sampling efficiency due to use of the same trees throughout the sampling day.

Seasonal Fluctuations

All species showed strong seasonal fluctuations of moisture content (fig. 3). These

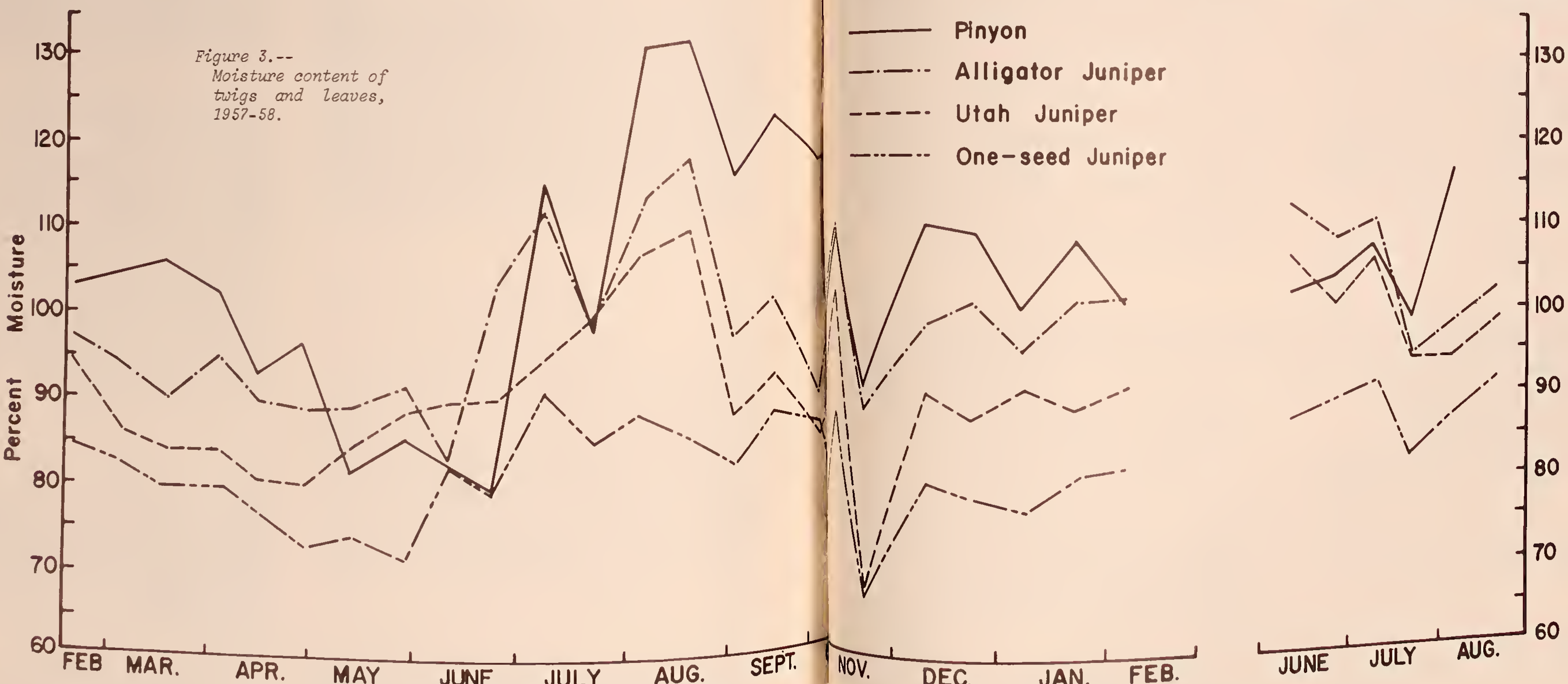

Figure 3.--Moisture content of twigs and leaves, 1957-58.

fluctuations were not clearly related to weather conditions as they were measured in this study. Multiple correlation and regression analyses with air temperature, vapor-pressure deficit, and soil moisture did yield significant correlation coefficients, but prediction equations from these analyses did not give accurate estimates of moisture content. Some of the coefficients were illogical or nonsignificant; for example, the soil-moisture coefficient was not consistent in sign and was in all cases nonsignificant. Vapor-pressure deficit and temperature were both positively related to moisture content at one site and negatively related at the other. The value of the constant terms in the regression equations was also quite different for the different species.

These results agree with those of Philpot (1963), who found no correlation between soil moisture and moisture content of P. ponderosa twigs. However, Namken (1964) and Philpot (1963) did find significant correlations with weather factors and cotton and Arctostaphylos viscida, respectively.

Because of these discrepancies, the data were also subjected to canonical analyses (table 2). These analyses resulted in more consistent equations than did the regression analyses. For the species with a significant correlation, the coefficients of vapor-pressure deficit were negative and the coefficients of soil moisture were positive, which are logical. The values of the constant terms were more consistent between species. Even though the equations were better, the correlation coefficients were still low, little of the total variation was accounted for by the equations, and estimated values of moisture content often did not follow the actual values.

Pinyon had a moisture-content pattern (see fig. 3) very similar to the long-term mean precipitation pattern for the study area (see fig. 1), but this fluctuation in moisture was not related to precipitation that actually fell during 1957. For example, pinyon twigs and leaves reached the lowest moisture content during May and June. Not even temporary upturns in moisture content were apparent, even with over 2 inches of rain in May and a June storm of 1 inch (interpolations from U.S. Weather Bureau records at Walnut Canyon, Arizona). In September, by way of contrast, there was no rainfall but moisture content was near the maximum for the study period.

Some of the changes in moisture content may have been related to growth of succulent young leaders. New and old growth were not separated in these samples, so the discrepancies introduced by new growth cannot be adequately evaluated. Supplemental samples

Table 2.--Correlation coefficients and equations (by canonical analysis) of the relationship of seasonal changes of moisture content of pinyon and junipers with vapor pressure deficit (VPD), temperature (T), T^2, and soil moisture (SM)

Species	Correlation coefficient	Equation
Utah juniper	0.560*	$Y = 74.26 - 1.28\ VPD + 0.03\ SM + 0.19\ T + 0.0013\ T^2$
Alligator juniper	.317	$Y = 97.33 + 10.33\ VPD - 0.09\ SM - 0.01\ T + 0.0001\ T^2$
One-seed juniper	.615*	$Y = 57.06 - 4.96\ VPD + 0.14\ SM + 0.18\ T + 0.0034\ T^2$
Pinyon	.499	$Y = 65.82 - 46.80\ VPD - 0.57\ SM + 0.57\ T + 0.0073\ T^2$

*Indicates significance at the .05 level.

of Utah juniper taken later, however, showed a slight rise in even old leaves during the summer on both wet and dry sites.

Summary

Seasonal and diurnal fluctuations in moisture content of twigs and leaves of pinyon and one-seed, Utah, and alligator junipers were determined. During the summer, junipers dried during the day in a moisture pattern which was inverse to air temperature. During the winter, junipers became more moist during the day. In general, pinyon did not show the regular diurnal patterns of the junipers.

Seasonal fluctuations of moisture content were not well correlated with temperature, vapor-pressure deficit, soil moisture, or precipitation which fell during individual storms. Some unmeasured attribute of the trees apparently was involved. All species had minimum moisture content in June and November, and peak moisture in July or August.

Literature Cited

Ackley, W. B.
1954. Seasonal and diurnal changes in the water contents and water deficits of Bartlett pear leaves. Plant Physiol. 29: 445-448.

Boyce, J. S.
1961. Forest pathology. Ed. 3, 572 pp. New York: McGraw-Hill Book Co.

Clark, J., and Gibbs, R. D.
1957. Studies in tree physiology. IV. Further investigations of seasonal changes in moisture content of certain Canadian forest trees. Can. J. Bot. 35: 219-253.

Gibbs, R. D.
1958. Patterns in the seasonal water content of trees. In The physiology of forest trees, ed. by K. V. Thimann. pp. 43-69. New York: Ronald Press Co.

Halevy, A.
1960. Diurnal fluctuations in water balance factors of gladiolus leaves. Bull. Res. Counc. Israel Sect. D. Bot. 8D: 239-246. [Biol. Abstr. 35: 68068.]

Kosikova, P. G.
1956. Water content in leaves and transpiration of perennial and annual cereals in relation to the growth of plants, and the effect of acid soil on them. Sbornik nauchno-Issled. Rabot Stud. Stavropolsk S.-Kh Inst. 1956 (4): 10-14. [Biol. Abstr. 35: 24784.]

Kramer, P. J., and Kozlowski, T. T.
1960. Physiology of trees. 642 pp. New York: McGraw-Hill Book Co.

Meyer, B. S.
1928. Seasonal variations in the physical and chemical properties of the leaves of the pitch pine, with especial reference to cold resistance. Amer. J. Bot. 15: 449-472.

Namken, L. N.
1964. The influence of crop environment on the internal water balance of cotton. Soil Sci. Soc. Amer. Proc. 28: 12-15.

Oppenheimer, H. R.
1953. An experimental study on ecological relationships and water expenses of Mediterranean forest vegetation. Palestine J. Bot. 8: 103-124.

Parker, J.
1954. Available water in stems of some Rocky Mountain conifers. Bot. Gaz. 115: 380-385.

____
1956. Drought resistance in woody plants. Bot. Rev. 22: 241-289.

Philpot, C. W.
1963. The moisture content of ponderosa pine and whiteleaf manzanita foliage in the central Sierra Nevada.* U.S. Forest Serv. Res. Note PSW-39, 7 pp. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Smith, H. V.
1956. Climate of Arizona. Ariz. Agr. Exp. Sta. Bull. 279, 99 pp.

Walter, H.
1955. The water economy and the hydrature of plants. Ann. Rev. Plant Physiol. 6: 239-252.

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